

Effect of Excitation Capacitor on Output Voltage of Self Excited Induction Generator (SEIG)

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Abstract— The increasing demand of electrical energy has attracted researchers, engineers and designer to focus and investigate further for clean energy sources. The conversion of renewable energy to electric involve use of generators. The concept of induction generator has been addressed by many researchers till date. Nowadays, demand is to further extend the application of induction machine as motor and induction generator in electric vehicles as well. During the regenerative breaking of electric vehicles, the induction machine can serve as induction generator provided appropriate capacity excitation is given. For an electric vehicle the actual speed varies depending upon road conditions, traffic and the driving skills. Hence the induction machine in such an application shall be capable of working as a generator for variable speed operations. The induction generator offers many advantages such as robust and maintenance free construction (squirrel cage), inherent overload protection, configurability etc. This paper discusses the effect of excitation capacitor on the output voltage of self-excited induction generator at variable speed and variable loading conditions. The experimental results of a case study are presented.

Index Terms— Induction generator, self-excitation, excitation configuration, voltage regulation

I. INTRODUCTION

Three phase induction motors are the most commonly used motors in the industry [1]. In fact, it is an induction machine that may be used as either induction motor or induction generator. The induction motor works as generator when turned with suitable prime mover and given proper excitation. The reactive power demands of induction generator can be supplied by either grid or through the capacitors [2, 3]. Fixed capacitors were used in the early induction generator designs as the excitation source. High power switching devices are now readily available, allowing induction generators to be equipped with adjustable excitation and operate in isolation steadily with the right controls to provide the regulated output [4 - 5]. Considering the torque speed characteristics of typical induction machine, the motoring operation occurs in a stable manner in the region of the speed torque curve below synchronous speed. The power and torque output of the motor vary in relation to the motor speed. At synchronous speed, absolutely no power is transmitted. The speed torque curve reverses if the induction motor is spinning faster than the synchronous speed. The mechanical input power from the prime mover is used to produce electric power in the stable zone of this curve [10, 11].

The generator stator windings must receive the excitation current in addition to the prime mover [6]. The output voltage is a function of the value of excitation current. Therefore, in order to have a constant bus voltage, either

the excitation current must be controlled or the output power must be kept at certain levels.

II. SELECTION OF EXCITATION CONFIGURATION

For providing the self-excitation to the induction generator using capacitors [4, 8, 9] various configurations are; Star connected motor–star connected capacitor, Star connected motor–delta connected capacitor, Delta connected motor–star connected capacitor, Delta connected motor –delta connected capacitor, C–2C configuration, Single capacitor excitation and Series capacitor scheme with all above configurations. Out of the available excitation configurations, star connected motor and delta connected capacitor excitation configuration scheme is chosen. The excitation scheme is illustrated in Figure 1.

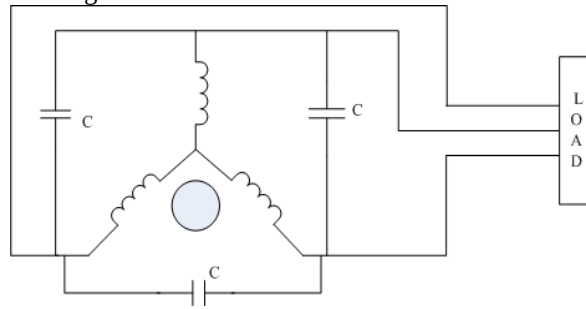


Figure 1 – Star Delta (Y-Δ) Configuration of SEIG

III. CAPACITOR CALCULATIONS

The capacitor required for the self-excitation of induction generator is calculated from the induction machine ratings by using simple power relations in the induction motors. The ratings of any induction machine can be taken from the name plate on the machine [5]. For the selected induction machine, the ratings are:

A. Induction Motor Ratings:

RPM : 1440RPM

Power : 2.2 KW three phase

Voltage: 415 V

Current: 4.6A

Star connected, squirrel cage induction motor.

$$P = \sqrt{3} V I \cos \phi$$

$$\phi = \cos^{-1} \left(\frac{P}{\sqrt{3} V I} \right)$$

$$\therefore \phi = 48.7$$

$$\text{Re active Power} = \sqrt{3} V I \sin \phi$$

$$\text{Re active Power} = 2484\text{VAR}$$

$$\text{Reactive Power per phase} = \frac{\sqrt{3} V I \sin \phi}{3}$$

$$\text{Reactive Power per phase} = 828.\text{VAR}$$

$$\text{Capacitor Current} = \frac{\text{Per phase reactive power}}{V}$$

$$\text{Capacitor Current} = 1.99\text{A}$$

$$\text{Capacitive Reactance} = \frac{V}{\text{Capacitive Current}}$$

$$\text{Capacitive Reactance} = 207.9\Omega$$

$$Capacitor (C) = \frac{1}{2 \pi f X_c}$$

$$\therefore Capacitor (C) = 15.30 \mu F$$

With the calculated values of the capacitors, the configuration is selected as shown in fig 1. The load is connected across the excitation capacitor 'C'. Though, the values of the capacitors calculated as explained earlier, the trial-and-error method is deployed to know the effect of excitation capacitor on the voltage output by the machine. For experimental trials, capacitors of capacitance values 10 μ f, 15 μ f, 20 μ f, 25 μ f, 30 μ f, 35 μ f and 40 μ f are chosen for excitation.

IV. EXPERIMENTAL SETUP

The experimental setup is shown in figure 2. Here, a three-phase squirrel cage induction motor is mechanically coupled with 220V, 8.5A, 2.2KW, 1500 RPM DC shunt motor which is operated as a variable speed drive. DC shunt motor works as a prime mover to provide mechanical motion to the induction motor. The three-phase induction motor is configured in star connected motor and delta connected capacitor excitation configuration and hence works as an induction generator.

V. EXPERIMENTATION: OBSERVATION AND RESULTS

During the experimentation, at first, the experimentation setup is run by using DC motor as a prime mover and manually adjusting the speed of the DC motor # induction generator set for obtaining the terminal voltage around 415V. The value of excitation capacitor per phase is varied from 15 μ f to 45 μ f at constant load. Table 1 shows corresponding set of observation of excitation capacitance, speed of induction generator and output voltage at constant load. It can be seen that, as the value of excitation capacitor increases, induction generator can generate voltage at lower speeds. i.e., inverse relation can be established between speed and capacitor value.

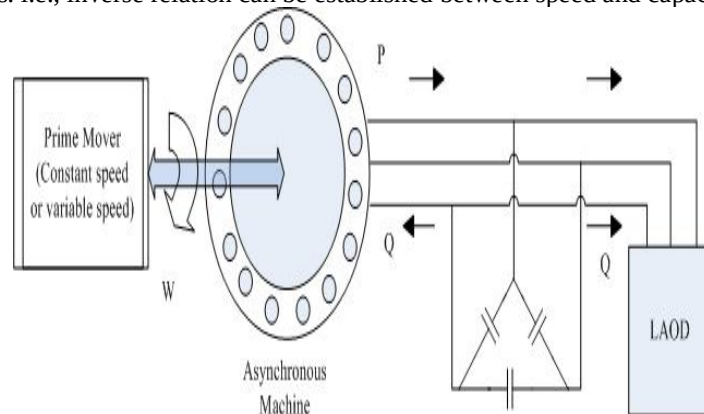


Figure 2: Experimental setup of DC shunt motor # 3 phase induction motor with capacitive excitation

TABLE I: SPEED VS CAPACITANCE AT CONSTANT VOLTAGE

Sr. No.	Capacitor (μ f)	Speed (RPM)	Generator Voltage (V)	Load (W)
1	10	1211	422	100
2	15	1108	416	100
3	20	1012	423	100
4	25	978	419	100
5	30	950	416	100
6	35	921	421	100
7	40	878	417	100
8	45	824	419	100

In the second step, the motor – generator set was set to operate at a constant speed, constant load and the value of excitation capacitor per phase was varied from 10 μf to 45 μf . The corresponding values of the terminal voltage output of induction generator are noted and are mentioned in table 2. It can be clearly seen that at constant speed and constant loading conditions, the output voltage of induction in direct proportion with the values of the excitation capacitor.

TABLE II: CAPACITANCE VS VOLTAGE AT CONSTANT SPEED AND CONSTANT LOAD

<i>Sr. No.</i>	<i>Capacitor (μf)</i>	<i>Speed (RPM)</i>	<i>Generator Voltage (V)</i>	<i>Load (W)</i>
1	10	955	216	100
2	15	952	312	100
3	20	950	382	100
4	25	952	406	100
5	30	950	417	100
6	35	945	438	100
7	40	956	467	100
8	45	944	490	100

The table 3 shows the observation of output voltage of the induction generator under varying loads when the motor – generator set is operated at constant speed and constant capacitive excitation.

TABLE III: VOLTAGE VS LOAD AT CONSTANT CAPACITOR 20 μf AND CONSTANT SPEED

<i>Sr. No.</i>	<i>Speed (RPM)</i>	<i>Generator Voltage (V)</i>	<i>Load (W)</i>
1	1344	480	0
2	1348	466	50
3	1346	456	100
4	1347	440	150
5	1348	401	200
6	1350	390	250
7	1350	372	300

A graph of voltage plotted for various values of excitation capacitor for fixed speed operation of induction generator is shown in figure 3. The graph indicates that, as the value of excitation capacitor increase, a corresponding increase (in direct relation) is found in terminal voltage of self-excited induction generator.

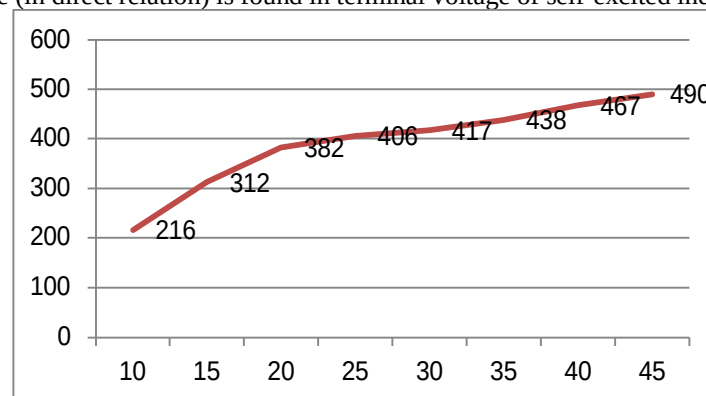


Figure 3: Capacitance Vs Output Voltage of SEIG at constant speed

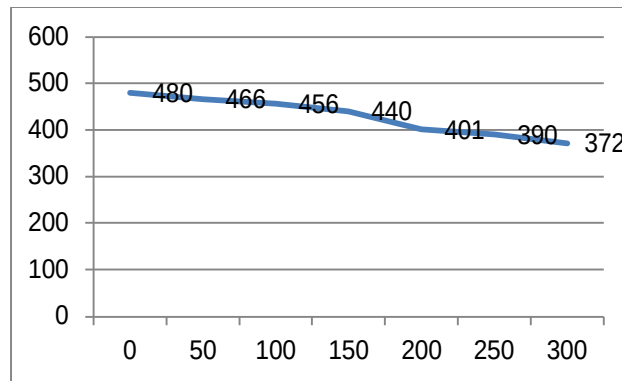


Figure 4: Load Vs Output Voltage of SEIG at constant speed

VI. CONCLUSION

The effect of excitation capacitance on magnitude of terminal voltage of self-excited induction generator is discussed in this paper. For constant speed operation, it is seen that as the value of excitation is increased, the voltage generated also increases. However, with constant excitation, at constant speed, the value of generated voltage decreases with increase in load. From table 1, it can also be concluded that for maintaining the voltage constant at varying speeds, excitation capacitor is required to be varied. Thus, for development of voltage regulator these considerations are required to be considered for excitation control and load control.

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